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A SURVEY OF THE AQUATIC VEGETATION AND BENTHIC MACROINVERTEBRATES OF THE CRINAN CANAL, WITH PARTICULAR REFERENCE TO THE EFFECTS OF SEAWATER INPUTS

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INTRODUCTION

The 15 km-long Crinan Canal links Ardrishaig and Crinan in Argyll across the northern end of the Kintyre peninsula. The eanal was opened in 1801 allowing boat traffic to take a short cut between Loch Fyne and the Sound of Jura, thus avoiding a lengthy voyage around the Mull of Kintyre. Fifteen locks permit boats to ascend and descend the 20 m to the canal summit, which lies between Cairnbaan and Dunardry. Loss of water through the locks is made up from reservoirs in Knapdale Forest to the south. Nowadays the canal is used mainly by pleasure craft.

Summer water shortages are a long-standing problem in the operation of the canal. During dry periods in summer, particularly when boat traffic has been heavy, pressure on water resources has led to draught restrictions and restricted locking for canal users. In order to overcome these problems, British Waterways has for several years pumped saline water from the River Add estuary into the western reach of the canal. A new fixed back-pumping station has recently been installed above Lock 14 at Crinan which automatically pumps water from the estuary into the canal when water levels in the latter drop to a critical point.

The effects of these regular introductions of saline water on the ecology of the freshwater Crinan Canal are unknown. Salinity monitoring carried out by British Waterways in summer 1997 showed that the effects of pumping brackish water from the Add estuary were restricted to the 5 km between Locks 14 and 13 (Halat, 1997). No studies were carried out on the ecological impact of the pumping.

There is little information available on the impact of saline inputs on other British canals. The westernmost section of the Leeds & Liverpool Canal, in Liverpool, formerly received inputs of Mersey estuary water. Here, strong salinity stratification was observed with a saline layer penetrating eastwards along the canal bed in mid-channel, but the water along the margins was much less affected (Dr J.W. Eaton, University of Liverpool, personal communication). Most plant growth (mainly *Ceratophyllum demersum, Myriophyllum spicatum* and the filamentous alga *Cladophora*) was concentrated along the margins and there was little evidence of impact, although these plants have some degree of tolerance of mild brackish conditions anyway (Sculthorpe, 1967). Effects on invertebrates were more substantial with invasion of estuarine species; while barnacles were reported to have established on the canal walls close to the Stanley Dock entrance to the canal (although the evidence suggested that they were unable to reproduce successfully).

In 1999, the Scottish Environment Protection Agency (SEPA) commissioned a survey of the Crinan Canal to assess the effects of the new and historical pumping regimes on the aquatic vegetation and benthic macroinvertebrates of the canal, and to examine the feasibility of using these communities as indicators of the scale and extent of any such impact. The survey also provided an opportunity to assess the overall distributional status of aquatic plants and macroinvertebrates throughout the canal.

METHODS

The entire length of the Crinan Canal was surveyed during 5 - 6 August 1999. The abundance of each aquatic plant species present was recorded per 200 - 250 m stretch of canal (lengths varied slightly owing to the presence of locks, but 64 sites were defined) using an abundance scale of 1 = present; 2 = moderate abundance; 3 = highly abundant. A grapnel on a 10 m length of cord was used to retrieve plants from deep water. Conductivity was recorded at every site using a portable field instrument. In addition, Ekman grab samples of sediment and submerged vegetation were taken at 10 sites to assess benthic macroinvertebrate distribution (Fig. 1). These samples were sorted in the field using a nest of sieves. The more obvious macroinvertebrates were picked out and preserved in 70% alcohol. These specimens and the preserved sample residues were delivered to the SEPA laboratory at East Kilbride for further examination and identification. Water conductivity was recorded at each sampling point, using a field-portable meter.

RESULTS & DISCUSSION

Distribution of aquatic plants

The most striking feature of the distribution of aquatic plants in the canal was the contrast between the stretch of the canal west of Lock 5 at Cairnbaan and the stretch to the east (Fig. 2). For reasons discussed below, the aquatic vegetation in the summit and western reaches was scanty and generally of lower diversity than in the eastern reach. In addition to the higher diversity of aquatic plants generally occurring at sites east of Lock 5, there was a greater overall abundance of individual species. *Sparganium angustifolium* showed this pattern very clearly. Some species such as *Alisma plantago-aquatica*, *Potamogeton praelongus* and *Potamogeton natans* were restricted to the eastern stretch, although others (e.g. *Typha latifolia* and *Nymphaea alba*) showed the opposite distribution. It is possible that these latter two species have been deliberately introduced to the canal as ornamentals in the vicinity of the canalside dwelling 200 m east of Crinan Bridge.

Distribution of macroinvertebrates

At three of the 10 sites sampled by Ekman grab, the substrate was rocky and no macroinvertebrates were collected (Table 1). At most of the remaining sites, both taxon richness and abundance were low. The samples taken near Bellanoch and Oakfield Bridges contained the richest and most abundant fauna. Of the 18 taxa recorded, only the snails *Potamopyrgus jenkinsi* and *Lymnaea peregra*, naidid and tubificid worms and chironomid larvae were found at three sites or more.

The canal as a habitat for aquatic vegetation and macroinvertebrates

Several factors combine to make the Crinan Canal a rather hostile place for aquatic plants, particularly in its summit and western reaches.

First, the canal is heavily used by powered craft, with traffic concentrated during the summer (plant growth) period. Boat traffic probably exceeds the critical range of 2,000 - 4,000 movements ha^{-1} $year^{-1}$, identified by work elsewhere on the UK canal network, as producing a substantial negative impact on aquatic vegetation (Murphy & Eaton, 1983; Murphy, 1992; Murphy *et al.*, 1995). However, the ecological impacts of boat traffic on the Crinan Canal ecosystem will be reduced, compared with powered craft impacts in most other navigable UK waterways (Murphy *et al.*, 1995), by three factors. These are as follows:

1. The canal is deep and wide. This means that the wave energy and other disturbance effects of a boat moving along the canal are reduced because of the greater volume of water to absorb the disturbance, in comparison with boat effects on canals of smaller cross-sectional area.

2. Most of the craft using the Crinan Canal are sea-going yachts. These have a streamlined and rather small hull cross-section, both of which produce a smaller wake compared with the cabin cruisers and canal barges which use most other UK canals.

3. Much of the canal bed and banks are rocky, either deliberately armoured or simply because the canal has been cut through rock. In addition, regular dredging takes place. The net effect is that there is less sediment in the canal (much less in many reaches) than in typical canals. Resuspension of sediment due to disturbance caused by moving craft is therefore greatly reduced (also because of the other two factors noted above). Silt resuspension, which reduces underwater light availability for plant photosynthesis, is a major cause of growth reduction for submerged plants in most UK canals that are heavily used by powered craft. It does not appear to be a feature of the Crinan Canal.

Second, the rocky and stony substrates which are a prominent feature of the summit and western reaches are inherently unfavourable as a habitat for aquatic plant growth. The 1999 survey showed that aquatic plants in these stretches tended to be limited to sites where local accumulations of silt occurred. These include corners of lock ponds, bays and offside (landward) banks of the canal where armouring was less of a feature. Running alongside the estuary shore, the canal tends to leak to the seaward side, leading to a concentration of armouring along the towpath bank.

Third, the depth and generally steep sides of the canal, coupled with the dark, peat-stained water of the system means that there is very limited room for submerged plant colonization within the photic zone. The photic limit for submerged plants (3% of surface light on average) is probably reached at less than 1 - 2 m in the Crinan Canal, whieh would make most of the canal bed uncolonizable by submerged plants. Often, much of the limited underwater space suitable for colonization along the sloping banks is occupied by emergent plants or floating-leaved plants such as *Sparganium angustifolium*, which outcompete submerged species. It was very noticeable that submerged plants in the western reach only showed any profusion of growth in the few places where substantial areas of shallower water occurred (notably Bellanoch Bay). Submerged plants were virtually absent from the summit reach, which is basically a long, rocky trench with virtually no suitable places for submerged plants to colonize. Conditions are better in the eastern reach (constructed along a raised beach, with less rocky substrate and more areas of shallow water).

Fig. 1 Map of Crinan Canal showing locations of macroinvertebrate sampling sites.

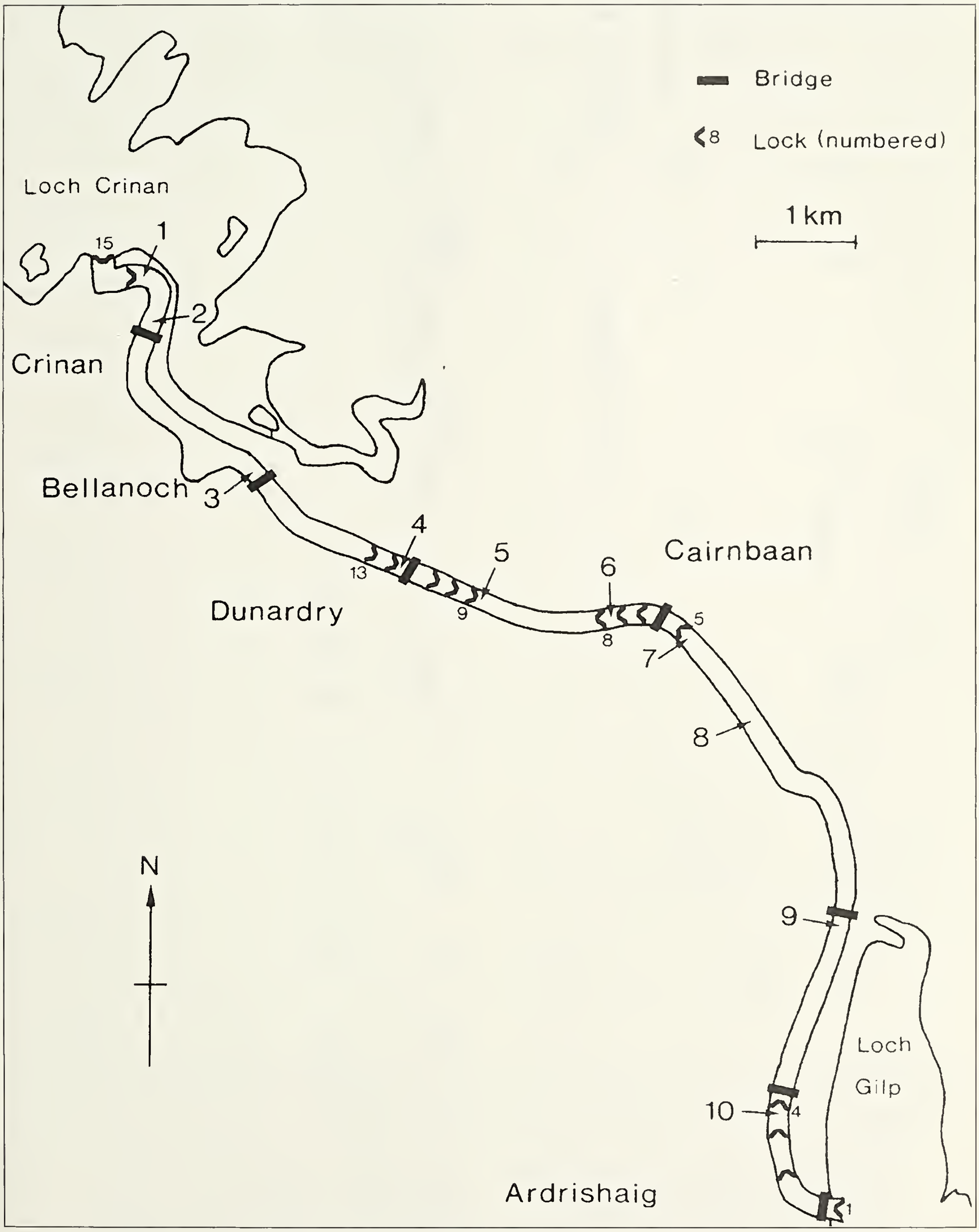

Fig. 2 Distribution of aquatic plants in the Crinan Canal, August 1999.

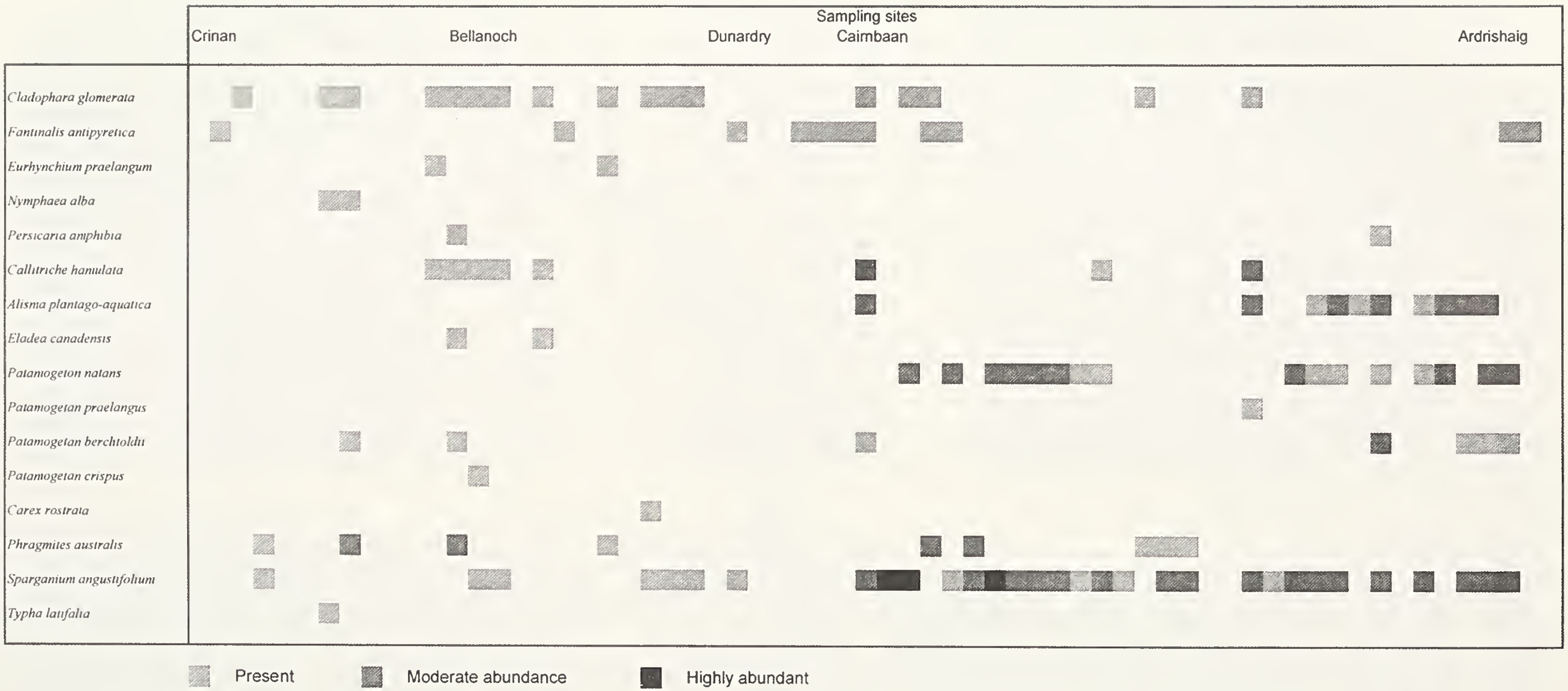

Table 1. Distribution of benthic macroinvertebrates in the Crinan Canal, August 1999 (+ present, ++ frequent, ++ abundant).

	1 NR7909 44	2 NR7949 38	3 NR8049 24	4 NR8209 12	5 NR8239 10	6 NR8349 08	7 NR8409 08	8 NR8488 99	9 NR8578 80	10 NR8518 59
Potamopyrgus jenkinsi		+	+++				+			
Lymnaea peregra		+					+	++		
Planorbis sp.									+++	
Sphaeriidae							+		+++	
Naididae					+			+	+	
Tubificidae					+		+	+	+	+
Lumbriculidae									+	
Helobdella stagnalis								+		
Asellus aquaticus							+	++		
Baetis rhodani			+							
Corixidae (nymphs)								+	+	
Haliplidae (larvae)		+					+			
Sialis lutaria			+							+
Hydroptila sp.			+							
Phryganea bipunctata								+		
Athripsodes cinereus								++		
Ceratopogonidae				+						
Chironomidae			++		+		+	+	+	+

The combined effects of boat traffic disturbance, unsuitability of substrate conditions, and problems of light availability for submerged plants mean that the canal, particularly in its summit and western reaches, is inherently unlikely to support the dense growth and high diversity of aquatic plant species which are characteristic of lowland Scottish canals (e.g. Ross *et al.*, 1986; Anderson & Murphy, 1987; Murphy *et al.*, 1987; Watson & Murphy, 1988). Particularly in its summit and western reaches, the canal ecosystem is already experiencing a fairly strong combination of disturbance (ecologically defined as any factor which damages plant tissue, e.g. boat waves in a canal system) and stress (any factor which limits plant photosynthesis, e.g. light limitation or presence of toxic ions such as salt in a freshwater system). Plants are quite good at resisting the effects of either increased disturbance or high stress intensities. Typically the plant assemblage present shifts to accommodate the new conditions by colonization of species best able to tolerate either disturbance or stress. However, plant communities are usually unable to tolerate a simultaneous combination of high stress and high disturbance (Dickinson & Murphy, 1998). In practice, what this means for a system like the Crinan Canal is that its aquatic vegetation is already living rather close to the edge of what is surviveable by plants. Increasing the intensity either of stress-causing conditions, or of disturbance, is consequently quite likely to have a major effect on the vegetation, leading to loss of plant cover and diversity from the system.

Adding a further stressor to the system in the form of saline water intrusion from back-pumping above Lock 14 is likely to increase the intensity of stress experienced by freshwater plants. If the scale (both frequency and quantity of seawater entering the system are important) of the back-pumping is great enough, freshwater species present are likely to be lost.

The probability of loss of individual species depends on how susceptible the plants are to saline stress, and also on their growth form. In general, plants with their foliage at or above the water surface are less susceptible to salinity-associated damage than plants with their vulnerable leaf tissue below the surface. *Phragmites australis* for example is quite tolerant of brackish conditions. *Nymphaea alba* and *Sparganium angustifolium* are less so, while none of the submerged species currently found in the canal have any significant salinity tolerance (Sculthorpe, 1967).

Some of the same features of the canal which limit the abundance and diversity of aquatic plants (e.g. the rocky bed in the western half of the canal and the regular dredging) also conspire to make the canal a relatively inhospitable environment for benthic macroinvertebrates. The reduced habitat diversity resulting from the scarcity of aquatic vegetation in large parts of the canal also partly explains the relatively impoverished macroinvertebrate fauna. Representatives of 18 macroinvertebrate families were found during this survey, compared with 43 families recorded in the Forth & Clyde Canal during summer 1980 (SEPA unpublished data).

The high variability between sites in the richness and abundance of the macroinvertebrate fauna undoubtedly reflects the limited and patchy distribution of soft sediments. The grab sampling method used would not have been effective where the canal bed was rocky or covered with only a thin layer of soft sediments. The absence or scarcity of certain groups such as water beetles, dragonflies and hemipteran bugs can be attributed to the sampling method used. It is highly probable that sweep sampling of the canal margins using a long-handled pond net, particularly in the more well-vegetated areas, would have increased the taxon list considerably.

Possible impact of seawater back-pumping

In 1999, both *Sparganium angustifolium* and *Phragmites australis* occurred in a side basin of the canal some 400 m above the back-pumping discharge. *Nymphaea alba* occurred some 200 m east of Crinan Bridge, about 1 km above the discharge. No submerged vascular plants were found closer than 1.2 km above the discharge (*Potamogeton berchtoldii*, 400 m east of Crinan Bridge). One unhealthy-looking clump of the aquatic moss *Fontinalis antipyretica*, and isolated fragments of green filamentous algae (*Cladophora*) were the only submerged plants found anywhere in the westernmost kilometre of the canal. The sediment in this stretch was very black and anoxic, probably as a result of the decomposition of leaf litter: the landward bank of the canal here is heavily wooded. The only macroinvertebrate species found in grab samples taken from west of Crinan Bridge was a single specimen of the snail *Potamopyrgus jenkinsi*, a euryhaline species which in Scotland spread from brackish to fresh waters during the first half of the 20th century (Hunter & Warwick, 1957).

It should be borne in mind that the extreme western end of the Crinan Canal is already inherently a poor place for aquatic plant growth (especially submerged plants). However, it is quite likely that back-pumping has made growth conditions in the canal more difficult for these plants. The presence of the highly-visible floating plants (*Sparganium angustifolium* in the bay 400 m east of the pump discharge and Nymphaea alba in the bay adjacent to the canalside dwelling some 200 m east of Crinan Bridge, with a second population occurring a further 200 m east) may provide convenient markers of possible future changes associated with back-pumping. Should either population show substantial damage or loss in the absence of other likely causes of damage, this could be an indication of increased salinity impact on the system.

At present there is no indication of any damage which might be associated with back-pumping above a point about 400 m east of Crinan Bridge (i.e. about 1.2 km above the pump discharge). Bellanoch Bay (1.4 km east of Crinan Bridge and about 2.2 km above the pump discharge) has a diverse and, for the Crinan Canal, abundant community of aquatic plants, including three submerged species. Potentially the whole of the western streteh below Lock 13 is at risk, since saline water would reach as far east as this lock. The grab sample taken from this stretch just west of Bellanoch Bridge had the second highest macroinvertebrate taxon richness and abundance of those collected from the canal, although the sample was heavily dominated by the salt-tolerant snail *Potamopyrgus jenkinsi*. More intensive sampling of this stretch using other methods (e.g. sweep netting) would be required to more clearly establish if the saline discharge were having a significant effect on the macroinvertebrate fauna.

The limited evidence of a conductivity survey undertaken during 5 - 6 August 1999 (when no back-pumping was taking place) suggests that no enhancement of conductivity was present at this time further east than Bellanoch Bay. Both of the sea lock ponds at the two ends of the canal had strongly brackish water with 4 - 5 mS cm^{-1} conductivity. In contrast, conductivity in most of the canal (from above Lock 1 to Bellanoch Bay) was in the range 0.1 - 0.2 mS cm^{-1}. The stretch from Bellanoch Bay to Lock 14 showed a conductivity up to three times higher than the rest of the canal, peaking at around 0.3 mS cm^{-1} west of Crinan Bridge. While this is still a low value in absolute terms, it provides evidence for a residual effect most likely to have been produced by previous back-pumping of seawater into this stretch.

If seawater is indeed responsible for a loss of submerged freshwater plants from the westernmost kilometre of the canal, it is an interesting question as to whether in the longer term there may be a colonization of this currently empty habitat by plant species tolerant of fluctuating salinity conditions. Since the pumping (and even more so automatic pumping by the permament installation) is a recent development, and colonization by new species takes time, it is unsurprising that nothing as yet has successfully invaded. However, there are several plants which may do so. Prime candidates are *Potamogeton pectinatus* and *Ruppia maritima*, both of which can tolerate elevated salinity. The latter is an estuarine species, the former less tolerant of constant brackish conditions, but well adapted to a habitat in which brackish and freshwater conditions alternate on a regular basis. Both plants are common around the Scottish seaboard and may successfully colonize watercourses influenced by engineering operations (e.g. weir construction) which alter the balance of freshwater-to-saline conditions in rivers and other coastal watercourses (e.g. the Wick River, Caithness: Murphy, 1993). It remains to be seen whether the combination of other, non-saline stress and disturbance conditions occurring in this stretch of the Crinan Canal would be too great to allow such saline stress-tolerant plants to successfully colonize.

CONCLUSIONS

In August 1999, an end-to-end survey of the Crinan Canal recorded 16 species of aquatic plants present, including one filamentous alga and two aquatic moss species. In addition, 18 macroinvertebrate taxa were collected.

The aquatic flora of the canal was dominated by floating-leaved rooted species, particularly *Sparganium angustifolium*. The emergent *Phragmites australis* was also widespread. Restricted distributions were shown by two other dominant species: emergent *Alisma plantago-aquatica* and floating-leaved rooted *Potamogeton natans*, occurring only in the eastern stretch between Locks 1 and 5. Submerged plants were much less abundant, especially in the summit and western stretches, and were completely absent from the westernmost 1.2 km of the canal.

There was evidence that water quality in this westernmost stretch was being impacted by seawater back-pumping. Although no pumping appeared to be going on at the time of sampling (overflow weirs were running, suggesting that water was not in short supply) there was elevated conductivity in this stretch, suggesting a residual effect of earlier pumping. Recorded conductivities were never higher than 2 - 3 times the average of 0.13 mS cm^{-1} for the rest of the canal. In contrast, values of >4.0 mS cm^{-1} were recorded on the landward sides of Locks 2 and 15 which are regularly influenced by seawater inflow when the sea locks are used.

The impact of back-pumping on aquatic vegetation of the westernmost stretch of the Crinan Canal is measurable but limited. This stretch of canal is already a hostile environment for aquatic vegetation owing to its physical characteristics. However, the complete absence of submerged vascular plants (and virtual absence of filamentous algae or mosses) up to 1.2 km east of Lock 15 may be a consequence of the seawater incursions produced by back-pumping when water levels are reduced.

The presence of some floating-leaved rooted vegetation and emergent plants at two locations within this stretch suggests that the impact to date has not been excessive, and these conspicuous stands of vegetation (especially *Nymphaea alba*) might provide a useful and easily-monitored marker for future impact. If they show signs of damage or disappear, this could indicate enhanced saline impact in the vulnerable stretch of canal.

The benthic macroinvertebrate fauna at most sites was relatively impoverished, reflecting the lack of soft sediments and the limitations of the sampling method used. The results were therefore inconclusive. Further investigations would be required to ascertain whether seawater back pumping was having a significant impact on the macroinvertebrate community west of Lock 13.

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